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Special Articles on Release 15 Standardization
—Advancements in the Completed Initial 5G and LTE/LTE-Advanced Specifications—

# NR Physical Layer Specifications in 5G

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A Work Item of the detailed specifications of 5G RAN for 5G commercial services is being conducted in 3GPP. The non-standalone NR specifications, which enable early deployment of NR carriers by exploiting LTE/LTE-Advanced carriers as the master node carriers, were completed in December 2017. In June 2018, the standalone NR specifications, which require full NR functionality and do not rely on LTE/LTE-Advanced carriers, were also completed. In this article, we present the NR physical layer specifications.

## 1. Introduction

With the spread of smartphones and tablet terminals, it has become easier for people to collect information and enjoy rich contents such as videos and music at any time and in any location. The quality of the content available to these terminals has also been improved dramatically. Furthermore, it is expected that services made possible by the "Internet of Things" (IoT) era, where everything is connected to networks, will become increasingly important in the future.

Under such circumstances, the 3rd Generation Partnership Project (3GPP) formulated the New Radio (NR) standard for wireless communication in 5th Generation mobile communication systems (5G), which doesn't have backward compatibility with LTE and LTE-Advanced. NR supports various use-cases such as enhanced Mobile BroadBand (eMBB), Ultra-Reliable and Low-Latency Communications (URLLC), and massive Machine-Type Communications (mMTC), over a very wide frequency range from below 1 GHz to 52.6 GHz. This article describes the underlying technologies from the physical layer perspective of NR that are specified to realize these requirements from the various use-cases.

## 2. Frame Structure/Duplex Mode

### 2.1 Support for New Subcarrier Spacings

NR adopts a radio access scheme called Orthogonal Frequency Division Multiplexing (OFDM)[*1], which is the same scheme used in LTE. To adapt to services requiring low latency and to enable the use of higher frequencies (including millimeter-wave[*2] frequencies), NR supports higher subcarrier[*3] spacings of 30, 60, 120, and 240 kHz based on the LTE subcarrier spacing of 15 kHz. Note that a subcarrier spacing of 240 kHz is only used for Synchronization Signal (SS)[*4]/Physical Broadcast CHannel (PBCH)[*5] blocks, as described later (In addition, the SS/PBCH block does not support a subcarrier spacing of 60 kHz).

When user equipment initially accesses the network, it detects an SS/PBCH block by assuming a subcarrier spacing that can be set in this carrier, and based on the PBCH detected in this block, it identifies the subcarrier spacings of the control/data channels, etc.

### 2.2 Frame Structure

In NR, multiple OFDM symbols[*6] are used to construct slots[*7], subframes[*8], and frames[*9]. A slot consists of 14 OFDM symbols for the given subcarrier spacing, a subframe is defined as a 1 ms interval, and a frame is defined as 10 subframes. These relationships are shown in **Figure 1**.

In the frequency domain, a resource block consists of 12 consecutive subcarriers for the given subcarrier spacing.

In NR, unlike LTE, the frame structure is not dependent on the duplex mode[*10]. In other words, it uses a common frame structure regardless of the duplex mode.

NR provides much greater flexibility than LTE in the uplink and downlink patterns of Time Division Duplex (TDD)[*11] communication. It is possible to semi-statically or dynamically set various uplink/downlink patterns by the system information and/or by user-specific higher layer signaling[*12] and/or L1 signaling[*13].

It is also possible to perform TDD communication without using higher layer/L1 signaling to indicate the uplink/downlink patterns. The user equipment can recognize the direction of uplink/downlink communication based on periodic transmission and reception that are configured by higher layer signaling and/or indicated by dynamic signaling in the physical layer.

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*1 OFDM: A multi-carrier modulation format where information signals are modulated with orthogonal subcarriers. A type of digital modulation scheme where information is split across multiple orthogonal carriers and transmitted in parallel. It can transmit data with high spectral efficiency.

*2 Millimeter waves: Radio frequency band with wavelengths in the range of 1 to 10 mm.

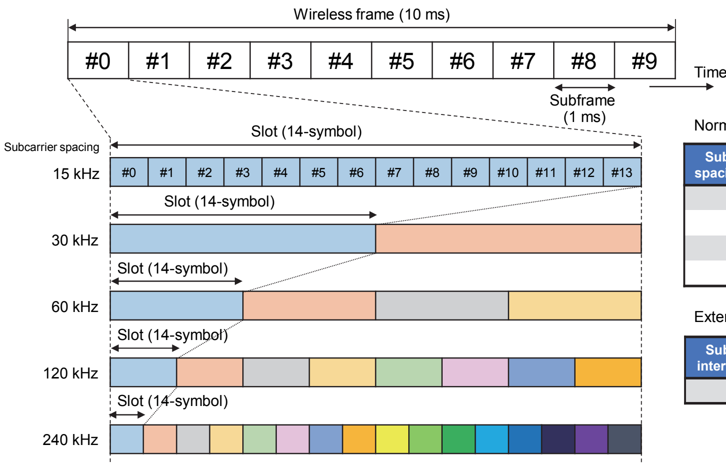
*3 Subcarrier: Each carrier in a multi-carrier modulation system that transmits bits of information in parallel over multiple carriers.

*4 SS: A physical signal enabling the mobile station to detect cell frequency, reception timing, and cell ID in order to begin communications when powering up.

*5 PBCH: A channel for broadcasting essential wireless parameters for receiving control channel and corresponding shared channel (such as system frame number, control channel configuration including sub-carrier spacing and so on).

*6 OFDM symbol: A unit of transmission data consisting of multiple subcarriers. A Cyclic Prefix (CP) is inserted at the front of each symbol.

*7 Slot: A unit for scheduling data consisting of multiple OFDM symbols.




Normal cyclic prefix

| Subcarrier spacing [kHz] | No. of symbols per slot | No. of slots per subframe | No. of subframes per frame |
|---|---|---|---|
| 15 | 14 | 1 | 10 |
| 30 | 14 | 2 | 10 |
| 60 | 14 | 4 | 10 |
| 120 | 14 | 8 | 10 |

Extended cyclic prefix

| Subcarrier interval [kHz] | No. of symbols per slot | No. of slots per subframe | No. of subframes per frame |
|---|---|---|---|
| 60 | 12 | 4 | 10 |

**Figure 1　The relationship between slots, subframes and frames**

## 3. Initial Access and Mobility

A user equipment's initial access in NR is performed according to a procedure that involves the steps of detecting a Synchronization Signal (SS), acquiring broadcast system information[*14], and establishing connection with the network by a random access[*15] procedure.

### 3.1 SS/PBCH Block

As in LTE, the SS in NR consists of two signals: a Primary Synchronization Signal (PSS)[*16], and a Secondary Synchronization Signal (SSS)[*17]. The SS together with the PBCH and the DeModulation Reference Signals for PBCH (DMRS for PBCH)[*18] forms an SS/PBCH block as shown in **Figure 2**.

The base station uses this SS/PBCH block to provide information that is essential for initial access and mobility, including system parameters whereby user equipment can discover NR cells[*19], establish frame synchronization, measure the downlink reception quality, and carry out other actions necessary for the reception of system information. The base station can set the transmission timing and transmission period of the SS/PBCH block for each carrier, and indicates this information to the user equipment.

In NR, multiple resources for SS/PBCH block transmission are defined within a half frame of 5 ms duration, where the maximum number of SS/PBCH block transmissions per carrier depends on the frequency band. As shown in **Figure 3**, the number of SS/PBCH blocks to be transmitted can be set according to factors such as the base station

*8 Subframe: A unit of radio resources in the time domain, consisting of multiple slots.

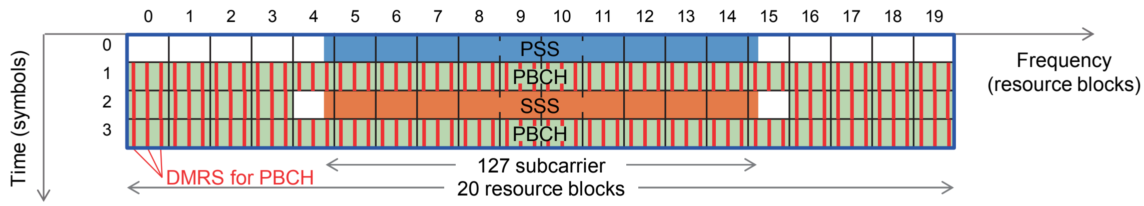
*9 Frame: The period in which an encoder/decoder operates or a data signal of length corresponding to that period.

*10 Duplex mode: A communication scheme where transmission can be performed in the uplink and downlink simultaneously. Generally implemented as Frequency Division Duplex (FDD) or Time Division Duplex (TDD) (see *11).

*11 TDD: A bidirectional transmit/receive system. This system achieves bidirectional communication by allocating different time slots to uplink and downlink transmissions on the same frequency.

*12 Higher layer signaling: In this article, upper layer signaling refers to messages that are transmitted and received in order to control terminals in the Medium Access Control (MAC) layer and higher layers. Examples include Radio Resource Control (RRC) messages and MAC control elements.

*13 L1 signaling: In this paper, L1 signaling refers to messages that are transmitted and received in order to control terminals at layers above the MAC layer. Examples include Downlink Control Information (DCI) and Uplink Control Information (UCI).




| Subcarrier spacing of SS/PBCH block | Transmission bandwidth of SS/PBCH block |
|---|---|
| 15 kHz | 3.6 MHz |
| 30 kHz | 7.2 MHz |
| 120 kHz | 28.8 MHz |
| 240 kHz | 57.6 MHz |

Figure 2　SS/PBCH block configuration

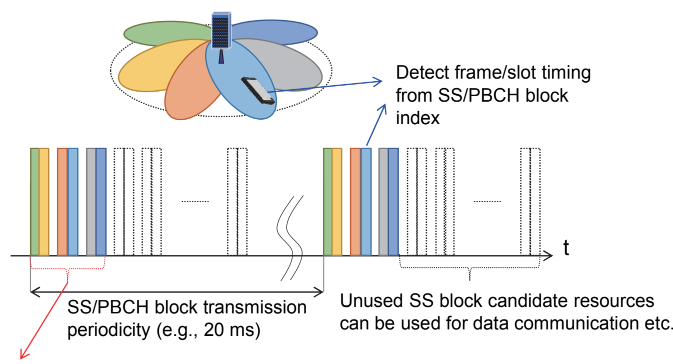



Figure 3　SS/PBCH block transmission configuration example

antenna configuration. With multiple SS/PBCH blocks, different beamforming[*20] can be applied to each SS/PBCH block in order to increase the communication range and expand the area of coverage.

## 3.2 System Information Notification

Broadcast information in NR can be classified into three types: broadcast information transmitted by the PBCH, system information necessary for initial access, and other system information.

The PBCH includes a System Frame Number (SFN)[*21] and information that user equipment needs to establish frame synchronization with a NR cell after detecting an SS/PBCH block, such as an index

*14 Broadcast system information: Essential system information (including cell access information required for executing the procedure for connecting mobile terminals to cells, random access channel information and so on) to be broadcast within a cell.

*15 Random access: A procedure executed by mobile terminals and base stations for connecting uplink signals and synchronizing their transmission timing.

*16 PSS: A known signal that the user equipment first searches for in the cell search procedure.

*17 SSS: A known signal transmitted to enable detection of the physical cell ID in the cell search procedure.

*18 DMRS for PBCH: A known signal transmitted to measure the state of a radio channel for PBCH demodulation.

*19 Cell: The smallest unit of area in which transmission and reception of wireless signals is done between a cellular mobile communications network and mobile terminals.

for identifying the symbol position of the detected SS/PBCH block in a half frame. The PBCH also carries system parameters that are needed for the reception of System Information Block[*22] type 1 (SIB 1), which is described below.

To perform random access, it is necessary to have information such as the uplink carrier information and random access signal configuration information. This is included as part of the information necessary for initial access, which is broadcast to the user equipment in an NR cell as SIB1.

## 3.3 Random Access

Random access in NR is performed in four steps in the same way as in LTE.

At the first step, the user equipment transmits a Physical Random Access CHannel (PRACH)[*23] to the base station. As shown in **Table 1**, NR defines 13 PRACH formats in total, including some formats with fixed subcarrier spacings that follow the design of LTE PRACH, and other formats with variable subcarrier spacings that can fit into the duration of an integer number of symbols in an NR slot.

When a base station is operated with beamforming where different beams are applied to multiple SS/PBCH block transmissions, different PRACH transmission resources are associated with different SS/PBCH blocks. User equipment transmits a PRACH to initiate random access by using the PRACH resource associated with the selected

Table 1 PRACH format

<table>
<tr><th>Format number</th><th>Sequence length</th><th>No. of OFDM symbol repetitions</th><th>Subcarrier spacing</th><th>Time duration</th><th>Bandwidth</th></tr>
<tr><td>0</td><td rowspan="4">839</td><td>1</td><td rowspan="3">1.25 kHz</td><td>1 subframe</td><td rowspan="3">1.05 MHz</td></tr>
<tr><td>1</td><td>2</td><td>3 subframe</td></tr>
<tr><td>2</td><td>4</td><td>3.5 subframe</td></tr>
<tr><td>3</td><td>4</td><td>5 kHz</td><td>1 subframe</td><td>4.20 MHz</td></tr>
<tr><td>A1</td><td rowspan="9">139</td><td>2</td><td rowspan="9">{15, 30, 60, 120} kHz</td><td>2 symbols</td><td rowspan="9">{2.09, 4.17, 8.34, 16.68} MHz</td></tr>
<tr><td>A2</td><td>4</td><td>4 symbols</td></tr>
<tr><td>A3</td><td>6</td><td>6 symbols</td></tr>
<tr><td>B1</td><td>2</td><td>2 symbols</td></tr>
<tr><td>B2</td><td>4</td><td>4 symbols</td></tr>
<tr><td>B3</td><td>6</td><td>6 symbols</td></tr>
<tr><td>B4</td><td>12</td><td>12 symbols</td></tr>
<tr><td>C0</td><td>1</td><td>2 symbols</td></tr>
<tr><td>C2</td><td>4</td><td>6 symbols</td></tr>
</table>

*20 Beamforming: A technique for increasing or decreasing the gain of antennas in a specific direction by controlling the amplitude and phase of multiple antennas to form a directional pattern with the antennas.

*21 SFN: A number allocated to each radio frame of 10 ms.

*22 SIB: A specific block of system information broadcast from an base station to mobile terminals. There are multiple types of SIBs.

*23 PRACH: A physical channel used by mobile terminals as an initial transmitted signal in the random-access procedure.

SS/PBCH block. In this way, the base station can use the received PRACH resources to figure out which SS/PBCH block (and thus which beamforming direction) was received by the user equipment transmitting a PRACH. Therefore, in the subsequent random access procedure consisting of random access response reception, connection request message transmission and contention resolution message reception, the base station can use transmission/reception beamforming directed specifically to the user equipment.

### 3.4 Mobility

In NR, as in LTE, the base station performs tasks such as selecting serving cells, performing handovers and adding/deleting secondary cells based on the report from corresponding user equipment regarding measurement results on downlink reference signals. The SSS included in the SS/PBCH block transmitted by the base station is a basic cell-specific reference signal in NR. The user equipment uses it to measure and report the Reference Signal Received Power (RSRP) and Reference Signal Received Quality (RSRQ) in each cell according to settings from the base station.

## 4. MIMO/Beamforming

### 4.1 MIMO Transmission Method

In the high frequency band, it is very important to obtain a high beamforming gain*24 by using many antennas to compensate for the effects of radio wave attenuation. The high frequency band of NR requires the use of Multiple Input Multiple Output (MIMO)*25 technology that assumes the availability of hybrid beamforming using up to 256 antenna elements at the base station and up to 32 antenna elements at the user equipment.

Hybrid beamforming is a technique that can reduce the cost of implementing circuits for beamforming in high-frequency bands. It consists of digital beamforming to perform signal control in the baseband, and analog beamforming to perform signal control in the RF (Radio Frequency). Since analog beamforming cannot be controlled in sub-band units due to implementation constraints, wideband beamforming is generally used.

To improve the spectral efficiency*26, it is essential to use spatial multiplexing in addition to beamforming. For the downlink, codebook*27 based closed-loop*28 precoding*29 is specified to accommodate up to eight layers of single-user MIMO*30 and up to twelve layers of multi-user MIMO*31. For the uplink, two transmission methods are supported, namely codebook-based and non-codebook-based transmission. It is possible to transmit up to four layers with single-user uplink MIMO. The non-codebook-based transmission method is designed by assuming beam reciprocity*32 is supported in the user equipment. The user equipment receives a downlink reference signal (RS) such as SS/PBCH blocks or Channel State Information RS (CSI-RS)*33, and determines the uplink precoder based on the received downlink RS.

### 4.2 Reference Signal Structure

The RS structure of NR basically follows that of LTE while achieving the flexibility to adapt to

*24 Gain: One of the radiation characteristics of an antenna. An indicator of how many times larger the radiation strength in the antenna's direction of peak radiation is relative to a standard antenna.

*25 MIMO: A signal transmission technology that improves communications quality and spectral efficiency by using multiple transmitter and receiver antennas to transmit signals at the same time and same frequency.

*26 Spectral efficiency: The number of data bits that can be transmitted per unit time and unit frequency band.

*27 Codebook: A set of predetermined precoding weight matrix candidates.

*28 Closed-loop: A method of using feedback information from receivers.

*29 Precoding: A process for improving the quality of signal reception by multiplying signals before transmission with weights according to the current radio propagation channel.

*30 Single-user MIMO: Technology that uses MIMO transmission at identical temporal frequencies for a single user.

operation in various different frequency bands and scenarios. An example of a downlink RS structure is shown in **Figure 4**.

If an RS is transmitted constantly, it may cause design constraints for possible RS and channel designs in future releases. Therefore, NR tries to avoid specifying an RS that is constantly transmitted (e.g., Cell-specific Reference Signal (CRS) in LTE), and implements function of CRS by using multiple RSs instead.

Specifically, the CSI-RS, DeModulation RS (DM-RS) and Tracking RS (TRS) are specified for channel state information estimation, data demodulation and time/frequency tracking, respectively.

DM-RS enables suitable tracking of a wide range of channel fluctuation speeds and is specified with a structure having a Front-Load (FL) DM-RS mapped in the front part of the data channel as well as additional mapping of 0–3 symbols of Additional (AD) DM-RS in order to suppress overheads[*34].

TRS has the same signal sequence generation with CSI-RS. However, TRS is transmitted in the intervals of 4 subcarriers and 4 OFDM symbols so that sufficient tracking accuracy is achievable with a reasonable overhead.

In high-frequency bands, phase noise[*35] would be a serious issue. Therefore, in NR, Phase-Tracking Reference Signal (PT-RS) is newly specified as a UE-specific reference signal.

## 4.3 Beam Control Techniques

Beam control in L1/L2[*36] can be divided into beam management and CSI acquisition.

Beam management is a particularly effective technique at high frequencies and is generally aimed at establishing and maintaining transmitting/

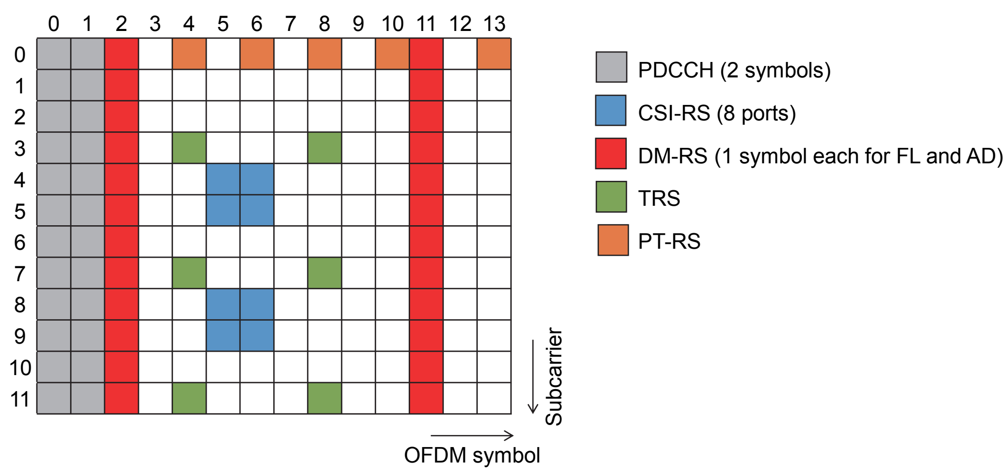



**Figure 4 Example of downlink reference signal configuration**

*31 Multi-user MIMO: Technology that uses MIMO transmission at identical temporal frequencies for multiple users.

*32 Beam reciprocity: A technique whereby radio equipment determines which transmitting beam to use based on information derived from the received beam.

*33 CSI-RS: A downlink reference signal used by mobile terminals to measure the state of the radio channel.

*34 Overhead: Control information needed for transmitting/receiving user data, plus radio resources used for other than transmitting user data such as reference signals for measuring received quality.

*35 Phase noise: Phase fluctuation that occurs due to frequency components other than those of the carrier frequency in a local oscillator signal.

*36 L2: The second layer of the OSI reference model (data link layer).

receiving analog beam pairs between the base station and user equipment. For example, the user equipment compares the L1-Reference Signal Received Power (RSRP)*37 of multiple SS/PBCH blocks and CSI-RS to which different beams have been applied by the base station, and selects a suitable transmit beam to be reported to the base station. The base station reports the beam information applied to the downlink channel, so that the user equipment can select the corresponding reception beam to receive the downlink channel. A beam failure recovery technique is also specified, whereby user equipment that detects deterioration in the characteristics of a base station beam can request a switch to a different beam.

On the other hand, CSI acquisition is used for purposes such as determining the choice of transmission rank*38, digital beams and Modulation and Coding Scheme (MCS)*39. The codebook used for digital beam control is specified as Type I and Type II, which have relatively low and relatively high quantization granularity*40, respectively. In Type II, information about two beams and their linear combination*41 information is reported to the base station, enabling beam control with higher spatial granularity.

## 5. Scheduling/HARQ

In NR, as in LTE, the downlink data channels and uplink data channels are scheduled based on the Downlink Control Information (DCI)*42. The DCI is transmitted and received via the Physical Downlink Control CHannel (PDCCH)*43. As in LTE, it is possible to use the frequency domain resource assignment field included in DCI to allocate frequency-domain resources in resource block units. In addition, in NR, the DCI is also able to indicate the time-domain resources for data channel scheduling.

The base station allocates a Physical Downlink Shared CHannel (PDSCH) to the user equipment and uses PDCCH to transmit downlink control information for the PDSCH. The user equipment receives and demodulates the PDCCH, and receives the PDSCH based on this downlink control information in the PDCCH. After receiving the PDSCH, the user equipment sends a Hybrid Automatic Repeat reQuest ACKnowledgment (HARQ-ACK)*44 to feed back the results of decoding. HARQ-ACK is transmitted via the Physical Uplink Control CHannel (PUCCH)*45, as are Scheduling Requests (SR)*46 and CSI. The PUCCH transmission timing and resources can also be indicated by the DCI in the same way as the data channel. **Figure 5** shows an example of data and HARQ-ACK resource allocation.

In HARQ retransmissions, in addition to the method whereby the entire transport block as initially transmitted and received is retransmitted, another method called code-block-group-based retransmission is specified. In code-block-group-based retransmission, when a transport block consists of multiple code blocks, only the code block groups that contain errors are retransmitted instead of retransmitting the entire transport block.

In general, uplink data scheduling is followed by scheduling request procedure, in which the user equipment transmits a SR using configured SR resources (**Figure 6** (a)). In this scheme, however,

*37 **RSRP**: Received power of a signal measured at a receiver. RSRP is used as an indicator of receiver sensitivity of a mobile terminal.

*38 **Transmission rank**: The number of layers (spatial streams) transmitted simultaneously in MIMO.

*39 **MCS**: Combinations of modulation scheme and coding rate decided on beforehand when performing Adaptive Modulation and Coding.

*40 **Quantization granularity**: The spatial granularity of beams that are capable of being formed.

*41 **Linear combination**: The linear sum of vectors. The vectors are multiplied by constant factors and added together.

*42 **DCI**: Control information transmitted on the downlink that includes scheduling information needed by each user to demodulate data and information on data modulation and channel coding rate.

*43 **PDCCH**: Control channel for the physical layer in the downlink.

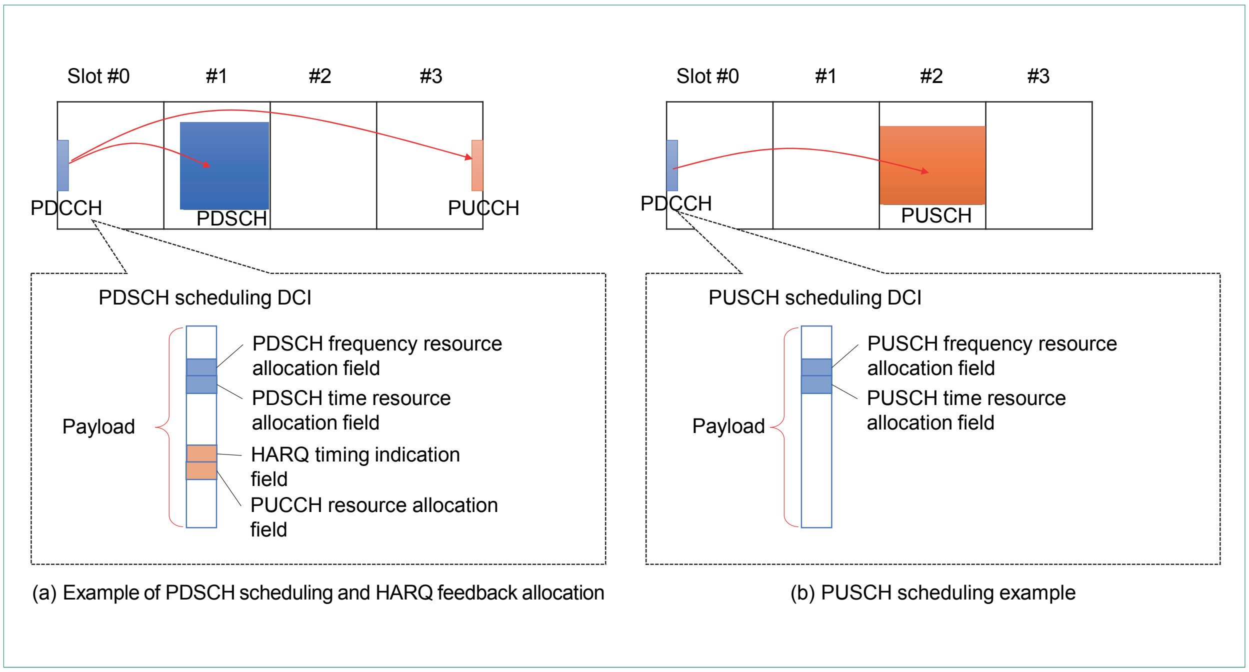



Figure 5　Example of resource allocation for data channel and HARQ-ACK

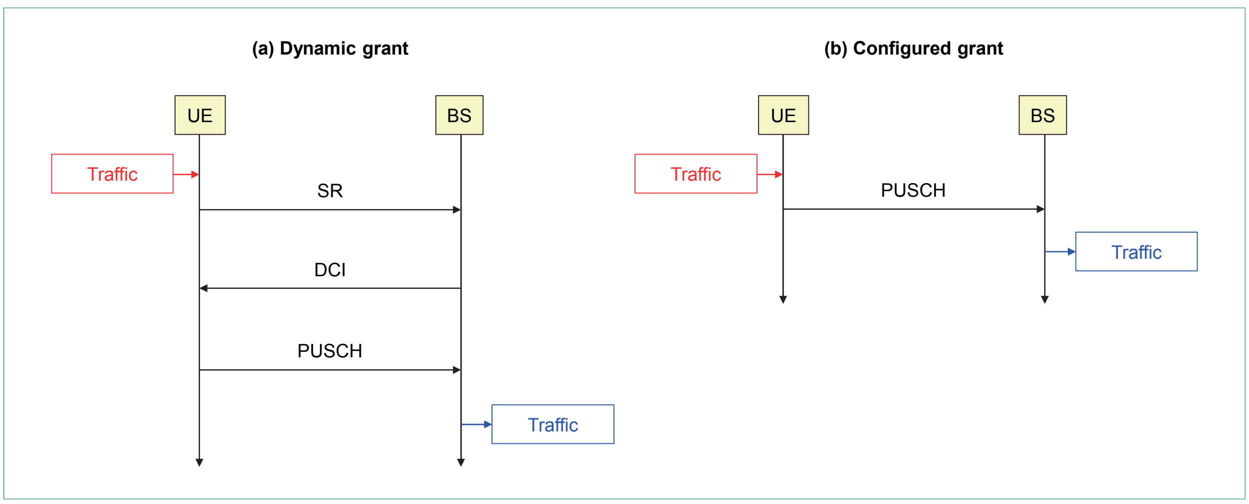



Figure 6　Dynamic grant and configured grant

there is an unavoidable delay due to the scheduling request step. Therefore, NR supports configured grants, whereby a Physical Uplink Shared CHannel (PUSCH)*47 resource is configured to a user equipment, and the user equipment can transmit a PUSCH with this allocated resource when uplink

*44 HARQ-ACK: A receive acknowledgment signal whereby a receiving node can tell the sending node whether or not the data was successfully received (decoded).

*45 PUCCH: Physical channel used for sending and receiving control signals in the uplink.

*46 SR: A signal from the user to the base station requesting radio resource allocation for uplink.

*47 PUSCH: Physical channel used for sending and receiving data packets in the uplink.

data traffic arrives without performing a scheduling request procedure (Fig. 6 (b)).

## 6. Modulation and Channel Coding Schemes

**Tables 2** and **3** show the modulation and channel coding schemes that can be used for NR downlink and uplink communication, respectively.

1) Modulation Schemes

As the primary modulation scheme*48, in addition to the schemes specified since Release 8 LTE, 256QAM and $\pi/2$-BPSK that are available in the latest LTE are also supported in NR.

For the secondary modulation scheme*49, the same scheme as in LTE — Orthogonal Frequency Division Multiplexing with a Cyclic Prefix (CP-OFDM*50) — is applied to the downlink channels. For the uplink channels, it is possible to apply

Table 2　Modulation schemes

| Secondary modulation scheme | Primary modulation scheme | Downlink | Uplink |
|---|---|---|---|
| CP-OFDM | $\pi/2$-BPSK | — | — |
| | BPSK | — | PUCCH format 1 |
| | QPSK | PBCH, PDCCH, PDSCH | PUCCH format 1/2, PUSCH |
| | 16QAM | PDSCH | PUSCH |
| | 64QAM | PDSCH | PUSCH |
| | 256QAM | PDSCH | PUSCH |
| DFTS-OFDM | $\pi/2$-BPSK | — | PUCCH format 3/4, PUSCH |
| | QPSK | — | PUCCH format 3/4, PUSCH |
| | 16QAM | — | PUSCH |
| | 64QAM | — | PUSCH |
| | 256QAM | — | PUSCH |

Table 3　Channel coding

| | Downlink | Uplink |
|---|---|---|
| LDPC | DL-SCH, PCH | UL-SCH |
| Polar coding | BCH, DCI | UCI (payload size ≧ 12) |
| Block coding | — | UCI (payload size < 12) |

*48 Primary modulation scheme: The method used to embed a digital data stream on a radio carrier wave.

*49 Secondary modulation scheme: The method for further manipulation of the primary modulated data for purposes such as frequency spreading.

*50 CP-OFDM: An OFDM method that adds a guard time (CP) between symbols to suppress inter-symbol interference caused by multipath propagation or the like.

both Discrete Fourier Transform Spreading OFDM (DFTS-OFDM), which suppresses the Peak-to-Average Power Ratio (PAPR)*51 to allow broader coverage, and the same CP-OFDM scheme as used in the downlink. This enables the use of unified access schemes in the downlink and uplink, resulting in simpler systems.

2) Channel Coding Schemes

Low Density Parity Check (LDPC) coding and polar coding are specified as the channel coding schemes in NR, in addition to the block codes that have already been used in LTE.

The LDPC coding scheme used in the data channel (DL-SCH: DownLink Shared CHannel, UL-SCH: UpLink Shared CHannel, PCH: Paging CHannel) is able to perform parallel processing to minimize decoding latency, and can thus operate close to the Shannon limit*52. The polar coding scheme used in the control channel (DCI, UCI/uplink control information with a payload size of 12 or more) and BCH (Broadcast CHannel) has less decoding computation complexity compared with the convolutional code used in LTE (TBCC: Tail-Biting Convolutional Coding*53), while exhibiting superior characteristics that approach the Shannon limit. The same block codes as used in LTE are applied to UCIs with a small payload size.

## 7. Transmit Power Control

### 7.1 Transmit Power Control Taking Beam Control into Consideration

In NR, since transmitting/receiving beams can be formed in both the base station and the user equipment, transmission power control*54 is specified by taking into consideration the beamforming operation, which causes beamforming gain variation when switching the transmitting/receiving beam.

The user equipment can use reference signals to which the transmitting/receiving beams are applied in order to estimate the path loss*55 including the beam gain. Specifically, the path loss is estimated by comparing the transmit power before applying the transmit beam with the received power after applying the receiving beam. By applying different transmitting/receiving beams to multiple reference signals, the reference signal to be used can be dynamically switched to adapt to path loss fluctuations caused by switching of the transmitting/receiving beams.

Also, as in LTE, fractional transmission power control is specified as a way of reducing the transmit power at cell edges where the path loss is large. For each transmitting/receiving beam, the power control related parameters can be set differently so that the path loss compensation and power offset can be optimized.

### 7.2 Distribution of Transmission Power between LTE and NR

Release 15 specifies an upper limit of transmit power based on guidelines for the protection of humans. For the case of simultaneous transmissions of LTE and NR in the same frequency range, the total power between LTE and NR shall be within a specified range of values [1].

In the Release 12 LTE DC, a user equipment can be configured with a minimum guaranteed power

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*51 PAPR: As the ratio of maximum power to average power, an index expressing the peak magnitude of the transmit waveform. If this value is large, the amplifier power back-off has to be large to avoid nonlinear distortion, which is particularly problematic for mobile terminals.

*52 Shannon limit (also known as "Shannon communication-channel capacity"): Theoretically derived from bandwidth and Signal-to-Noise (SN) ratio, the maximum amount of information that can be transmitted.

*53 TBCC: A type of error-correcting code; namely, a coding scheme that generates codewords by using convolution calculation.

*54 Transmission power control: A technique of controlling transmission power such that the Signal-to-Noise Ratio (SNR) and Signal-to-Interference and Noise Ratio (SINR) at the receiver exceed the required values.

*55 Path loss: Propagation path loss estimated from the difference between the transmitted power and received power.

for each CG (cell group), and the user equipment dynamically distributes the transmit power between CGs such that each CG can at least use the minimum guaranteed power. However, it is difficult for early commercial user equipment to support this, since it requires dynamic power sharing between LTE and NR transmitters. Therefore, Release 15 specifies a scheme whereby the base station semi-statically configures the maximum transmission power for each CG. The behavior of user equipment for power control could be different depending on whether the user equipment supports dynamic power sharing between LTE and NR.

When the user equipment has a dynamic power sharing capability, it adjusts the NR transmission power so that the instantaneous total power does not exceed the specified value. An example of dynamic power distribution is shown in **Figure 7**. When the maximum transmission power of LTE and NR ($P_{\mathrm{LTE}}$, $P_{\mathrm{NR}}$) and the specified total power

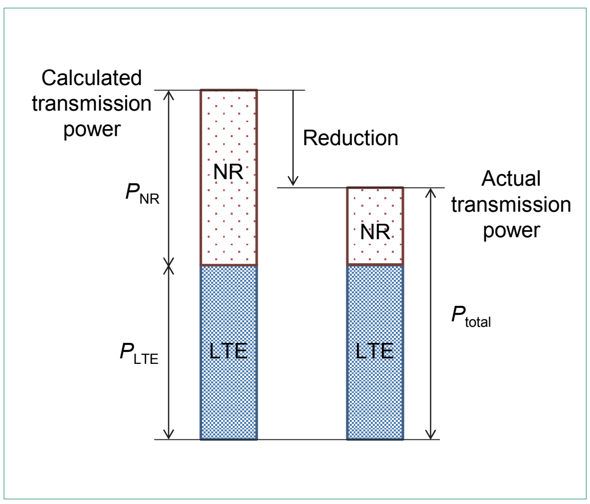


**Figure 7** Distribution of transmission power between LTE and NR

($P_{\mathrm{total}}$) have been set and the instantaneous calculated total transmission power exceeds $P_{\mathrm{total}}$, the NR transmission power is reduced so that the actual transmission power of the user equipment does not exceed $P_{\mathrm{total}}$.

Note that the base station is able to configure the LTE and NR maximum powers so that their total exceeds the specified value. However, if user equipment does not have the ability to perform dynamic power sharing, its uplink transmissions will be performed using time division multiplexing to switch between LTE and NR.

## 8. BWP/CA

In NR, the maximum bandwidth per carrier is much larger than in LTE: 100 MHz at frequencies below 6 GHz and 400 MHz at higher frequencies. For carriers operated with such a large bandwidth, NR supports the BandWidth Part (BWP) concept whereby user equipment can use smaller bandwidths than the carrier bandwidth used by the base station.

The base station uses higher-layer signaling to set up a BWP configuration (bandwidth, frequency position, subcarrier spacing) for the user equipment to use during communication. Different user equipment can be configured with different BWP configurations (**Figure 8**). The BWP configuration can be changed by higher layer signaling or L1 signaling. Therefore, even when the user equipment supports a sufficiently wide bandwidth, it is possible to set a narrower BWP configuration when there is no data traffic, thereby reducing the communication

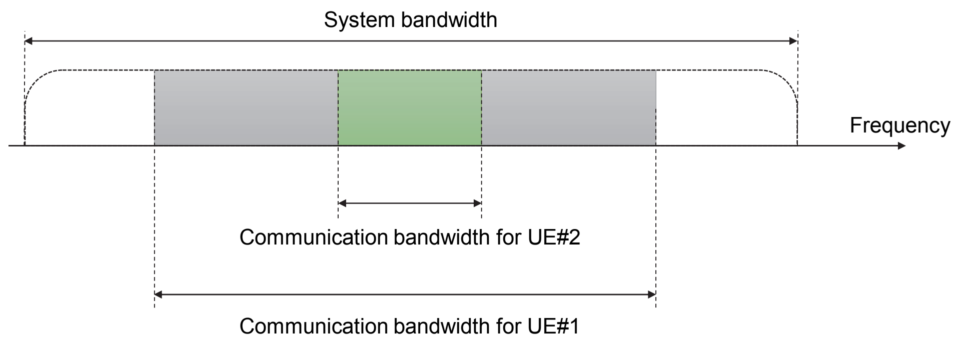


Figure 8 Bandwidth of an individual UE

bandwidth and power consumption.

In NR, Carrier Aggregation (CA)*56 is defined in the same way as in LTE. When CA is performed, BWP is configured for each Component Carrier (CC)*57. CA using CCs with different subcarrier spacings is also supported, making it possible to efficiently aggregate a wide range of frequencies ranging from existing cellular frequencies to millimeter waves.

## 9. Conclusion

This article has presented the NR Release 15 specifications, and the newly introduced functions in the physical layer. These functions make it possible to deliver the high speed, large capacity and low latency services that are expected for 5G. NTT DOCOMO will continue to promote the standardization activities of 3GPP to make further advances for 5G technologies to provide even lower latency and higher reliability for IoT applications, reduce power consumption, and improve direct communication between terminals.

### REFERENCE

[1] 3GPP TS38.101-1 V15.3.0: "NR; User Equipment (UE) radio transmission and reception," Sep. 2018.

*56 CA: A technology for increasing bandwidth and data rate by simultaneously transmitting and receiving signals for one user using multiple carriers.

*57 CC: Term denoting each of the carriers used in CA.